# Interface Pattern Selection Criterion for Cellular Structures in Directional Solidification (IPSIDS)

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## **Objectives**

This investigation focuses on to the key scientific concepts that govern the selection of cellular/dendritic patterns in directional solidification of alloys. Reliable theoretical models for cellular/dendritic growth are based on the diffusive transports of both heat and solute. However, thermosolutal convection effects generally dominate at low velocities so that it is not possible to obtain an unambiguous test of the diffusive model through experiments carried out under terrestrial conditions. It will be shown that the experimental conditions under which stable cellular structure form are precisely the ones where convection effects are dominant, so that microgravity environments are required for the comparison of experimental results with the theoretical predictions based on diffusive growth. The objective of this study is to obtain benchmark data under diffusive regime on cellular/dendritic growth and to analyze these data to precisely characterize the physics of the pattern selection process. In addition, conditions for planar to cellular and cellular to dendritic transitions under diffusive growth conditions will be precisely determined.

### Scientific Concepts

Theoretical models, based on solute and heat transport, give multiple solutions for cells and dendrites. In contrast, experimental studies show that a unique or a narrow set of solutions are selected. A second set of conditions, which takes into account the interface energy and its anisotropy, is required which defines the pattern selection criterion. It is this selection of a unique solution, or a certain narrow set of solutions, that is critical to the development of microstructures. The key problem is then to quantitatively establish the criterion that dictates this selection. This fundamental selection criterion for cellular structure is not understood. Furthermore, the precise role of surface energy, and its anisotropy, in the dendrite shape selection process has also not been established quantitatively. Since precise and reliable quantitative morphological measurements are possible only in the low velocity regime where convection effects are dominant, only microgravity experiments can give unambiguous data. Analysis of these benchmark data will allow us to establish the precise physics of the pattern selection process.

## Microgravity Need

The need for microgravity has been established to obtain cellular and dendritic growth under diffusive conditions. We shall present numerical calculations and critical experimental studies to demonstrate the role of convection under terrestrial conditions. In an Al-Cu alloy, directionally solidified upwards, a highly curved macroscopic interface forms due to the fluid flow which prevents any meaningful quantitative information on the microstructure formation. An experimental technique has been developed in which a number of samples of different diameters can be solidified simultaneously so that the effect of sample diameter, or the Rayleigh Number, on microstructure development can be established quantitatively. These experimental studies showed the presence of significant convection effect when the Al-Cu sample diameters were larger than 1 mm. Numerical calculations of fluid flow have also been carried out that show significant fluid flow for sample diameters larger than 1 mm. Sample diameters required for diffusive growth are of the same order of magnitude as the primary spacing, so that no selection of spacing occurs. Thus, microgravity studies are required to understand the physics of the spacing selection process. Detailed numerical studies of convection have been carried out and it is shown that for a sample of 1.0 cm diameter, microgravity level of  $10^{-4}$  g is required to obtain diffusive growth.

### Theoretical Models

Numerical models have been developed to predict the characteristics of cellular microstructures under steady-state growth conditions. These numerical models also predict the condition for the cellular to dendritic transition condition.

## **Proposed Experiments**

The proposed experiments will be carried out in the Al-4.0 wt% Cu system for which the physical constants have been accurately measured. A matrix of experimental studies, based on terrestrial experiments, will be presented. Directional solidification studies will be carried out for different growth rate and thermal gradient conditions. The sample will be quenched and microstructure scales and composition profiles will be accurately measured. The results will be compared with the theoretical model to establish the precise microstructure selection criterion.

### **Ground-Based Results**

The effect of growth rate and temperature gradient on cellular growth characteristics and on cell to dendrite transitions, observed under 1g conditions will be discussed for experimental studies in bulk samples of Al-Cu and in thin samples of succinonitrile-acetone.